Fisheries and Oceans Canada / Pêches et Océans Canada
Science / Sciences

CSAS / **SCCS**

Canadian Science Advisory Secretariat / **Secrétariat canadien de consultation scientifique**

Research Document 2011/097 / **Document de recherche 2011/097**

Gulf Region / **Région du Golfe**

Assessment and status of Striped Bass (*Morone saxatilis*) in the Southern Gulf of St. Lawrence, 2006 to 2010

Évaluation de la situation du bar rayé (*Morone saxatilis*) dans le sud du golfe du Saint-Laurent, 2006 à 2010

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ISSN 1499-3848 (Printed / Imprimé)
ISSN 1919-5044 (Online / En ligne)

Canada

Correct citation for this publication:
La présente publication doit être citée comme suit :

Douglas, S.G., and G. Chaput. 2011. Assessment and status of Striped Bass (*Morone saxatilis*) in the Southern Gulf of St. Lawrence, 2006 to 2010. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/097. iv + 22 p.

ABSTRACT

The status of the Striped Bass (*Morone saxatilis*) stock in the southern Gulf of St. Lawrence is updated with new information collected annually between 2006 and 2010. Estimates of spawner abundance have averaged 50,000 (16,200 to 92,160 annual range) over the last 5 years (2006 to 2010) and 35,000 (12,550 to 92,160) over the last decade (2001 to 2010). Male Striped Bass continue to dominate the spawning run in most years. Striped Bass with fork lengths between 40 and 50 cm and ages between 3 and 5 years were the largest component of the spawners in all assessed years. Striped Bass over age 6 years and longer than 60 cm are present but not abundant. The estimate of total mortality for adult Striped Bass continues to be high (0.47) for this population and natural mortality is believed to be low. The proposed recovery limit (21,600 spawners in 5 of the last 6 years) and target (31,200 spawners in 3 of 6 years) for southern Gulf Striped Bass could be met for the first time in 2011.

RÉSUMÉ

Une mise à jour de la situation de la population de bar rayé (*Morone saxatilis*) du sud du golfe du Saint-Laurent est présentée en utilisant les données collectées depuis 2006 à 2010. Les estimés d'abondance de géniteurs se situent en moyenne à 50 000 (16 200 à 92 160 écart annuel) poissons durant les cinq dernières années (2006 à 2010) et à 35 000 (12 550 à 92 160 écart annuel) poissons durant la dernière décennie (2001 à 2010). Les bar rayé mâles sont toujours dominant parmi les géniteurs dans la plupart des années. Les poissons mesurant entre 40 et 50 cm et âgés entre 3 et 5 ans sont dominants dans la composante des géniteurs pour toutes les années évaluées. Des individus de bar rayé âgés de plus de six ans et de longueur supérieure à 60 cm sont présents mais en faible abondance. L'estimé de mortalité totale pour les bar rayé adultes de cette population demeure élevé (0,47) mais on croit que le niveau de mortalité naturelle sur ces poissons est bas. L'objectif limite (21 600 géniteurs dans au moins 5 des 6 dernières années) et l'objectif cible (31 200 géniteurs dans 3 des 6 années) de rétablissement proposés pour la population de bar rayé pour le sud du golfe pourraient être atteints pour la première fois en 2011.

INTRODUCTION

Striped Bass (*Morone saxatilis*) are widely distributed throughout the estuaries and coastal waters of the southern Gulf of St. Lawrence (southern Gulf) and exist at the northern limit of the species distribution. Genetic analyses and conventional tagging studies have indicated that this population is geographically isolated within the southern Gulf and distinct from any other Striped Bass population, including those in the U.S.A. and the only other remaining Canadian population which spawns in the Stewiacke River of Nova Scotia (Bradford et al. 2001; Wirgin et al. 1993; Wirgin et al. 1995). In 2004, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) recognized the Striped Bass of the southern Gulf as a designatable unit (DU) and evaluated its status as 'Threatened' (COSEWIC 2004).

With the exceptions of Striped Bass populations in the extreme southern end of its range (south of North Carolina) and those in freshwater, anadromy typifies the life history of the species (Merriman 1941). Anadromous Striped Bass leave wintering areas in spring and return to estuaries where spawning occurs at the upper extent of the salt wedge. The Northwest (NW) Miramichi estuary remains the only known spawning location for Striped Bass in the southern Gulf of St. Lawrence and their spring spawning migration to this river is annually predictable in time and space (Bradford and Chaput 1996; Robichaud-LeBlanc et al. 1996). Simultaneous spawning runs of alosids (Alewife, Blueback Herring, and American Shad) to the NW Miramichi River occur each spring and these are exploited commercially by fishers using trapnets in the estuary. Striped Bass, as well as many other species (Atlantic Salmon, Brook Trout, American Eel, Sea Lamprey, White Sucker, etc.) are intercepted in this fishery but are quickly and efficiently released which results in high survival of the bycatch. The combination of these factors have provided the rationale and platform for the southern Gulf of St. Lawrence Striped Bass stock assessment since 1993.

Southern Gulf Striped Bass are managed as a single biological unit. Efforts to rebuild their low spawner abundance during the mid 1990s resulted in the introduction of management measures, most notably the closure of directed commercial fishing in 1996, and the closure of recreational and Aboriginal food, social, and ceremonial (FSC) fisheries in 2000. The modest increase in spawner abundance since those measures took effect has lent itself to the perception that additional management has been positive for the population. There has been no change in the management regime for Striped Bass since the fishery closures described above. Striped Bass of various life stages continue to be intercepted in a variety of illegal, commercial, and Aboriginal FSC fisheries.

The objective of the current assessment is to update the status of the Striped Bass stock in the southern Gulf of St. Lawrence with new information collected annually between 2006 and 2010. New stock status information will help inform the outstanding listing decision for southern Gulf Striped Bass, provide the basis for the second COSEWIC evaluation of the species (Douglas and Chaput 2011), and contribute towards the management of the resource under the *Fisheries Act* in the interim.

METHODS

FIELD SAMPLING

Detailed sampling protocols and procedures can be found in previous assessments (Bradford et al. 1995; Bradford and Chaput 1996; Bradford and Chaput 1997; Bradford and Chaput 1998; Douglas et al. 2001; Douglas et al. 2003; Douglas et al. 2006) but the mark-recapture experiments and sampling protocols between 2006 and 2010 are described here. Similar to previous years, three tagging events before the official start of the gaspereau (Alewife and Blueback Herring) season were conducted each year between 2006 and 2009 inclusively. Striped Bass obtained for the marking component of the experiment involved contracting a commercial gaspereau fisherman from the NW Miramichi to operate one trapnet during the week preceding the official opening of the regular gaspereau fishing season. Tags were placed on adult Striped Bass between May 23 and 28 in 2006, between May 22 and 26 in 2007, between May 26 and 30 in 2008, and May 23 and 27 in 2009. Due to the earlier timing of the spring conditions in 2010 and visual accounts of spawning Striped Bass in mid May, no fisherman was contracted and no mark-recapture experiment was initiated that year. Tags applied in previous years that were observed during bycatch sampling were added to the pool of marks available for the mark-recapture experiment in each year (2007 n=3, 2008 n=22, and 2009 n=12).

The recapture phase of the experiment has been similar since 1993. At least 12 gaspereau trapnets distributed within the NW Miramichi River, between its confluence with the Southwest (SW) Miramichi River and a point 6.0 km upstream, have been and continue to be the regular bycatch sampling sites (Figure 1). As many of these trapnets as possible were visited and sampled during any one day of fishing throughout the gaspereau season (generally 5-6 trapnets per day during the four week season between the end of May and the end of June (Table 1)). All Striped Bass were counted during the fishing event and those carrying dorsal tags provided the recapture information necessary to estimate the size of the spawning population. Bycatch sampling occurred daily until approximately June 10 in all years, then roughly corresponded to every other day until the end of the season.

A considerable decrease in Striped Bass bycatch and a higher proportion of spent individuals has generally been interpreted as the end of spawning and that the majority of Striped Bass have returned to the coastal environment. The timing of this out-migration has varied annually but has typically been consistent during the second week of June. The Striped Bass bycatch after this point is largely comprised of young males which often remain in the system until the end of the fishery (Bradford and Chaput 1996). Acoustic tracking of individual Striped Bass has also demonstrated that post-spawned females leave the Miramichi system rapidly after spawning while males remain in the estuary for a significantly longer period of time (Douglas et al. 2009). The potential bias that this sex-specific behaviour may introduce in the estimation of population size has been addressed by constraining catch and mark-recapture data to the period prior to out-migration when the majority of fish are believed to still be in the system (Table 1).

The collection of biological information from the spawning stock has always been attempted early in the season when samples are considered to be the most representative of the population. The pre-gaspereau season tagging events have generally provided an adequate means of collecting the necessary biological information (fork length, gender, and scales for ageing) in the past and did again in 2007, 2008, and 2009. In 2006, only 19 Striped Bass were

captured after 8 consecutive soak days (May 20-May 28) before the opening of the gaspereau season. This necessitated the opportunistic sampling of Striped Bass in gaspereau catches during the regular season. A total of 291 Striped Bass from 15 catches between May 29 and June 2, 2006 were used to derive the sex ratio and fork length distribution of spawners in that year. In 2010, Striped Bass were captured and sampled at a DFO index trapnet located at Cassilis in the upper portion of the NW Miramichi estuary beginning on May 18, one week before the opening of gaspereau season. Daily samples (n=985) of Striped Bass at this facility between May 20 and May 30 provided the basis for the 2010 sex ratio and fork length distribution of the spawning stock. In all years, Striped Bass lengths and scales, additional to those sampled during tagging, were collected opportunistically in the gaspereau fishery to augment the length at age information.

SPAWNER ABUNDANCE ANALYSES

Two separate indices of Striped Bass spawner abundance have been used in previous assessments and have been repeated here for the 2006 to 2010 sampling period. Mark-recapture data from any one day of sampling were first combined and then used in a sequential Bayes framework to derive the estimate (Gazey and Staley 1986). Secondly, the catch data were standardized to a unit of effort (bass per trapnet per 24 hours) and then treated with a general linear model (see details in Douglas et al. 2006). For years 2006 and 2010 when little or no mark recapture data were available, the linear relationship between both indices was used to derive an estimate of spawner abundance.

A hierarchical Bayesian model which incorporates both catch and mark and recapture data from single traps has been proposed as a better method of estimating the size of the spawning run to the NW Miramichi River, particularly when the mark and recapture data are poor (Chaput and Douglas 2011).

MORTALITY ESTIMATES

Similar to previous estimates of mortality for Striped Bass in the southern Gulf of St. Lawrence (Douglas et al. 2006), the instantaneous rate of mortality (Z) was calculated from the standard equation described by Ricker (1975):

$$Z = -Ln\left(\frac{N_{i,t}}{N_{i-1,t-1}}\right)$$

where $N_{i,t}$ = abundance of spawners at age i in year t

Annual survival (range 0 to 1) was calculated as e^{-Z} and annual mortality as 1 – S. Data inputs were derived from ages interpreted from scales of adult Striped Bass during their spawning migration to the NW Miramichi River in each year between 1994 and 2010. The number of spawners at age was calculated using the proportion at age and the spawner abundance as estimated by the hierarchal Bayesian model (Chaput and Douglas 2011). Median abundance at age (3 to 9 years old) for year-classes 1997 to 2007 were used to estimate mortality.

Acoustic tracking experiments designed to evaluate habitat use and behaviour of adult Striped Bass in the Miramichi system and throughout the southern Gulf have been conducted between 2003 and 2010 (Douglas et al. 2009). Consecutive spawning of Striped Bass, their high fidelity to the spawning grounds of the NW Miramichi River and the long battery life of transmitters has

provided an opportunity to monitor individual fish returning to spawn over consecutive years. Instantaneous rates of mortality (Z) for Striped Bass implanted in year 1 that returned to spawn in year 2 and year 3 were calculated as above.

RESULTS AND DISCUSSION

FIELD SAMPLING

The number of trapnet catches sampled for Striped Bass during the gaspereau fishery has been generally consistent over the history of the program and averaged 34% of total trapnet effort between 2006 and 2010 (Table 1). Sampling intensity was higher at the beginning of the fishery when catches of pre-spawning Striped Bass were assumed to be more representative of the population (Table 1).

The small catch of 19 Striped Bass during the tagging events of 2006 was unusual since the strategy to operate a single trapnet before the opening of gaspereau season (i.e. when no other trapnets are operating) has generally produced adequate numbers of Striped Bass for marking purposes. Given the increased catches of Striped Bass on May 29, 2006 (Appendix 1) it is possible that the tagging phase occurred too early to take full advantage of the spawning run.

A mark-recapture experiment was not initiated in 2010. Peak spawning is believed to have occurred during the week of May 16, one week before the opening of gaspereau season. Douglas et al. (2009) demonstrated the rapid descent of the estuary by female Striped Bass after spawning which suggests that many post-spawned Striped Bass had likely left the system and were not available to be captured or counted in the 2010 gaspereau fishery. Furthermore, female Striped Bass (n=14) that had been implanted with acoustic transmitters during the spring of 2008 and 2009 were detected leaving the estuary between May 20 and June 1, 2010 (average May 27, 2010), while males (n=10) were detected leaving between May 25 and June 26, 2010 (average of June 1, 2010) (DFO unpublished). It is expected that the warm spring temperatures and low freshwater discharge in 2010 resulted in the earlier than normal spawning event (Figures 2 and 3).

SPAWNER ABUNDANCE ESTIMATES

Sequential Baye's estimates (mode) of spawner abundance were 49,500, 100,000, and 56,000 in 2007, 2008, and 2009, respectively (Figure 4). These estimates match or exceed the highest values of the time series between 1993 and 2009 and represent a significant increase from low abundances estimated in the late 1990s. Catch per unit of effort (CPUE) estimates were also high during the 2007-2009 period and similar to previous high values of the time series (Table 2). The linear relationship (LnCPUE = 0.7371 x LnMark Recapture + 7.2981 (r^2 =0.73)) between spawner abundance as estimated by mark recapture and as estimated by CPUE resulted in population estimates of 13,690 in 2006 and 44,400 in 2010 (Figure 5). The estimate of spawners in 2010 is considered a minimum estimate and observations during sampling suggest the estimate is likely more representative of age-3 males recruiting to the population for the first time. The proportion of the spawning run that left the system and therefore not available to be counted when the gaspereau fishery opened is unknown but considered to be significant. Despite our perception of missing a component of the run in 2010, single trapnet catches were the highest (n=1,800) on record (Appendix 1).

The hierarchal Bayesian model proposed by Chaput and Douglas (2011) produced similar estimates of spawner abundance for the time series and for years with poor mark-recapture information (Table 3). However, we consider the hierarchal Bayesian approach to be a better method of estimating striped bass returning to the NW Miramichi River. The hierarchical model was able to estimate the catchability of individual trapnets which was then applied to the individual trapnet catches in years when mark and recapture data were poor or not available. The spawner estimates derived from the Bayesian hierarchical method have been brought forward here and used to evaluate abundance at age for estimates of mortality and year class composition.

RECOVERY LIMIT AND TARGET FOR SOUTHERN GULF STRIPED BASS

Based on a life history model that borrowed stock recruitment relationships from Striped Bass populations elsewhere, and assumed values of mortality, Douglas et al. (2006) proposed a recovery limit and target for southern Gulf Striped Bass, the latter being a level for which further access to the resource might be considered. The proposed recovery limit was a return of 21,600 spawners in 5 of 6 consecutive years while the return of 31,200 spawners in 3 of 6 consecutive years was proposed as the recovery target. The assumptions of the life history model and the lack of information specific to southern Gulf Striped Bass warrants the use of the lower confidence limit (2.5th percentile) of the population estimate to gauge against recovery objectives.

Levels of spawner abundance in 5 of the last 6 years (2005-2010) have not been sufficient to meet the recovery limit (Figure 6). A complete count of spawners was not possible in 2010 but is considered to have been sufficient to satisfy the recovery limit level of 21,600 spawners. If the population estimate's lower confidence limit exceeds 31,200 spawners in 2011, the criteria for both the recovery limit and target will have been met.

MORTALITY ESTIMATES

Total instantaneous mortality values (Z) ranged from a low of 0.08 to a high of 2.86 and corresponded to annual mortality rates of 7% to 94% (Table 4). Negative estimates of Z were frequent at age 3 and were not unexpected given the presumed maturity schedules for male and female bass at ages 3 to 5 resulting in partial recruitment to the spawning population of age-3 bass. There was a consistent bias in the spawner abundance estimates of 2000-2001, 2004-2005, and 2007-2008 as evidenced by the negative Z values along the diagonals of the age by year-class matrix (Table 4). This bias is the result of either an underestimate of spawners in 2000, 2004, and 2007, an overestimate in 2001, 2005, and 2008, or both. Alternatively, there may be no bias and proportionally more fish at age recruited to the spawning grounds in 2001, 2005, and 2008 relative to the previous year.

Based on the average abundance at ages 3 to 9 years over the period 1997 to 2010, the mortality of adult Striped Bass is in the order of 0.47 (Z = 0.63) (Figure 7). These values are marginally lower than estimates of Z (0.8-0.9) and A (0.5-0.6) previously calculated for southern Gulf Striped Bass between the ages of 3 and 7 (Douglas et al. 2006).

Estimates of mortality from Striped Bass that returned to spawn one year after they had been implanted with an acoustic tag are lower than estimates derived from the catch curve analysis above. In each of the five cases where tracking information was collected the year after Striped Bass were implanted, estimates of Z consistently ranged between 0.34 and 0.48 and corresponded to estimates of total mortality (A) of 0.28 to 0.38 (Table 5). The uncertainty

surrounding these estimates of mortality encompassed estimates derived from the catch curve analysis above. It is not clear why the estimates of Striped Bass mortality differ between the two methods. For example, both estimates of mortality were derived from the same sized and aged fish and samples were collected using the same trapnet method. There is no reason to suspect that the absence of fish older than 6 years of age on the spawning grounds is related to a sampling bias against larger bodied and older Striped Bass in gaspereau trapnets.

SIZE, AGE, AND SEX

The fork length distribution of Striped Bass sampled in the gaspereau fishery of the NW Miramichi River has been consistent since 2006 (Figure 8), since the adult monitoring program began in 1993, and since fishery closures in 1996 and 2000 (Chaput and Robichaud 1995). Striped Bass with fork lengths between 40 and 50 cm are most frequently sampled while those greater than 60 cm are much less abundant. The distribution of fork lengths around 30 cm, between 35 and 45 cm, and between 45 and 55 cm roughly correspond to Striped Bass aged 2, 3, and 4 years old, respectively (Table 6). Relationships between fork length and weight and gonad weight were provided from a sample of 72 Striped Bass gillnetted from the spawning grounds of the NW Miramichi River in spring 2008 (Figure 9). The earlier recruitment of age 3 males is usually responsible for their higher proportion on the spawning grounds in most years.

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
% male	0.94	0.92	0.63	0.37	0.69	0.83	0.69	0.64	0.77	0.58	0.51	0.69	0.40	0.87	0.93	0.58	0.41	0.89
% female	0.06	0.08	0.37	0.63	0.31	0.17	0.31	0.36	0.23	0.42	0.49	0.31	0.60	0.13	0.07	0.42	0.59	0.11

YEAR CLASS CONTRIBUTION

Male Striped Bass in the southern Gulf generally recruit at age 3 and females at age 4. In previous assessments, Striped Bass aged 6 and older were infrequent in samples. There has been some relatively strong recruitment of Striped Bass in the last decade, specifically the year classes of 2003, 2004, 2005, and 2007 have been well represented. The 2004 year class was the most abundant since monitoring began in 1993 and was well represented at ages 3 to 5 in 2007, 2008, 2009, respectively (Figure 10). Age 3 and 4 Striped Bass from the 2005 year class were also well represented in the spawning stock of 2008 and 2009. The strong recruitment of age 3 males in 2010 bodes well for the female component in 2011. Contributions to the spawning stock of Striped Bass aged 5 to 7 have improved since 2003 but remain low relative to younger age groups (Figure 10).

SUMMARY

The abundance of adult Striped Bass returning to the NW Miramichi River has been variable over the monitoring period with lowest levels (3 to 5 thousand spawners) observed in the late 1990s, and highest levels (13 to 92 thousand spawners) observed in the last decade. Spawner estimates in 2008 (92,200) and 2009 (50,200) match or exceed the highest estimate (50,000 in 1995) of the short time series (1993-2010). The spawner estimate of 2010 should be considered a minimum value because not all of the adult population was available to be counted.

In terms of status, 2011 is the earliest year that the proposed recovery limit and target for southern Gulf Striped Bass could be met.

Adult Striped Bass older than 6 years and larger than 60 cm are rarely sampled relative to younger animals.

The 2003, 2004, 2005, and 2007 year classes have been relatively strong. Recruitment of Striped Bass aged 3 to 5 years old appears to be good.

Despite closures of all Striped Bass fisheries, 30 to 50% of adults are estimated to be lost on an annual basis. Natural mortality of adult Striped Bass is unknown but considered to be low once they have reached age 2 or 3 (30-40 cm).

ACKNOWLEDGEMENTS

We continue to acknowledge the support and assistance from the commercial gaspereau fishermen of the NW Miramichi. DFO staff John Hayward, Joe Sheasgreen and Noella McDonald provided invaluable field and laboratory assistance. Students of the Northumberland Salmon Protection Association and DFO continue to make significant contributions to this field program.

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Table 1. Sampling details of the Striped Bass monitoring program in the NW Miramichi estuary 1993 to 2010. Indicated are the start and end dates for the gaspereau season, the entire sampling period, and the period from which mark-recapture and CPUE analyses were derived. Sampling intensity refers to the proportion of trapnet efforts sampled relative to the amount of trapnet effort expended, na indicates not available.

	Gaspereau season		Total sampling period					Mark-recapture / CPUE sampling period				
	Date		Date		Catches	Possible	Sampling	Date		Catches	Possible	Sampling
Year	Start	End	Start	End	sampled	samples	intensity	Start	End	sampled	samples	intensity
1993	na	na	28-May	18-Jun	46	na	na	28-May	16-Jun	37	na	na
1994	na	na	24-May	18-Jun	51	na	na	24-May	12-Jun	34	na	na
1995	na	na	24-May	21-Jun	64	na	na	24-May	9-Jun	31	na	na
1996	na	na	24-May	20-Jun	80	na	na	24-May	10-Jun	38	na	na
1997	na	na	4-Jun	20-Jun	61	na	na	4-Jun	20-Jun	61	na	na
1998*	18-May	20-Jun	21-May	17-Jun	82	na	na	21-May	4-Jun	46	na	na
1999*	18-May	19-Jun	21-May	18-Jun	135	273	49.5%	21-May	8-Jun	84	143	58.7%
2000*	18-May	21-Jun	25-May	21-Jun	102	220	46.4%	25-May	21-Jun	102	220	46.4%
2001*	18-May	22-Jun	25-May	20-Jun	32	102	31.4%	25-May	11-Jun	26	63	41.3%
2002*	22-May	26-Jun	23-May	19-Jun	56	240	23.3%	23-May	4-Jun	21	60	35.0%
2003*	20-May	24-Jun	24-May	24-Jun	75	233	32.2%	24-May	11-Jun	37	78	47.4%
2004	30-May	27-Jun	24-May	25-Jun	86	255	33.7%	24-May	11-Jun	28	69	40.6%
2005	29-May	26-Jun	24-May	24-Jun	85	272	31.3%	24-May	8-Jun	35	68	51.5%
2006	28-May	25-Jun	23-May	25-Jun	119	311	38.3%	23-May	2-Jun	30	61	49.2%
2007	27-May	24-Jun	22-May	23-Jun	93	244	38.1%	22-May	11-Jun	47	114	41.2%
2008	29-May	26-Jun	26-May	25-Jun	97	304	31.9%	26-May	16-Jun	65	190	34.2%
2009	27-May	24-Jun	23-May	24-Jun	91	281	32.4%	23-May	11-Jun	54	153	35.3%
2010	25-May	25-Jun	30-May	24-Jun	75	255	29.4%	30-May	12-Jun	49	123	39.8%

* Indicates years when the first two weekends of the season were closed to allow gaspereau escapement. A weekend refered to the period of time between noon on Saturday and 18:00 hrs. on the following Sunday.

Table 2. Median (and 95% Confidence Interval) annual catch of Striped Bass per net per day (Ln(CPUE)) in the gaspereau fishery of the NW Miramichi River. CPUE estimates and confidence intervals were back transformed from their natural logarithms.

	Ln (CPUE)				CPUE		
Year	Estimate	Lower 95% CI	Upper 95% CI	Std error	Estimate	Lower 95% CI	Upper 95% CI
1993							
1994	4.88	4.60	5.17	0.15	132	99	176
1995	3.76	3.32	4.19	0.22	43	28	66
1996	2.10	1.26	2.95	0.43	8	4	19
1997	1.55	0.52	2.58	0.52	5	2	13
1998	2.30	1.63	2.97	0.34	10	5	19
1999	2.44	1.85	3.04	0.30	11	6	21
2000	2.00	1.28	2.71	0.36	7	4	15
2001	3.83	3.44	4.23	0.20	46	31	69
2002	5.04	4.77	5.30	0.13	154	118	200
2003	4.01	3.64	4.37	0.19	55	38	79
2004	2.82	2.26	3.38	0.28	17	10	29
2005	3.13	2.61	3.66	0.27	23	14	39
2006	3.02	2.52	3.52	0.25	20	12	34
2007	4.38	4.12	4.63	0.13	79	62	103
2008	4.83	4.59	5.07	0.12	125	99	159
2009	4.04	3.71	4.36	0.17	57	41	78
2010	4.62	4.38	4.86	0.12	101	80	129

Table 3. Comparison of spawner abundance estimates derived by sequential and hierarchical Bayesian methods (hierarchal from Chaput and Douglas 2011).

Year	Bayesian sequential	Percentile 2.5	Percentile 97.5	Bayesian hierarchical	Percentile 2.5	Percentile 97.5
1993	5,500	4,550	7,300			
1994	29,000	23,000	47,000	55,200	7,392	604,200
1995	50,000	35,000	175,000	52,910	35,730	83,500
1996	8,090	6,275	13,370	3,675	851	15,480
1997	8,000	5,800	17,500	4,588	3,144	7,053
1998	3,400	2,900	4,800	3,845	3,061	4,924
1999	3,940	3,450	4,430	3,844	3,344	4,434
2000	3,900	2,850	5,250	4,290	3,305	5,671
2001	24,000	18,000	33,000	26,990	20,960	35,520
2002	29,000	25,500	32,500	26,600	23,650	29,960
2003	21,000	17,000	27,000	19,890	16,010	25,180
2004	15,000	10,000	24,500	12,550	9,054	17,840
2005	20,000	11,500	45,500	14,400	9,328	24,180
2006	13,700	3,800	49,650	16,200	5,385	49,590
2007	49,500	38,500	66,500	46,110	36,320	59,880
2008	100,000	70,000	130,000	92,160	73,600	117,900
2009	56,000	42,000	81,000	50,230	38,200	67,800
2010	44,400	11,700	168,500	45,120	14,670	134,300

Table 4. Estimates of Z and corresponding A values for Striped Bass year classes 1991-2006. Shaded boxes on the diagonals depict systematic biases in population abundance estimates.

		Year-class															
Parameter	**Age**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Z	3	-0.22	2.86	-1.95	1.15	0.83	0.09	-2.38	-0.39	0.08	0.84	0.00	-1.26	0.16	-0.01	0.52	1.15
	4	2.43	1.94	0.44	0.61	0.59	-0.57	1.26	1.19	2.00	-0.09	1.08	0.42	-1.02	0.90	1.45	
	5	0.75	-0.72	1.34	0.38	-0.88	1.04	2.62	2.54	-0.21	0.41	1.85	-0.60	1.13	1.88		
	6	1.98	1.64	1.10	-0.57	1.99	2.55	1.11	-1.20	0.65	1.54	-1.50	2.17	1.98			
	7	1.52	0.26	-1.38	1.11	0.57			1.30	1.08	-1.01	1.60	-1.05				
	8		-1.67	0.31	1.26				0.42	-1.13	1.12	-0.63					
	9		2.21						-0.03		0.83						
A	3	-0.25	0.94	-6.04	0.68	0.57	0.08	-9.54	-0.48	0.07	0.57	0.00	-2.51	0.15	-0.01	0.40	0.68
	4	0.91	0.86	0.36	0.46	0.44	-0.76	0.72	0.70	0.87	-0.09	0.66	0.34	-1.77	0.59	0.77	
	5	0.53	-1.06	0.74	0.32	-1.40	0.65	0.93	0.92	-0.23	0.34	0.84	-0.83	0.68	0.85		
	6	0.86	0.81	0.67	-0.77	0.86	0.92	0.67	-2.32	0.48	0.78	-3.47	0.89	0.86			
	7	0.78	0.23	-2.98	0.67	0.43			0.73	0.66	-1.75	0.80	-1.85				
	8		-4.30	0.27	0.72				0.35	-2.10	0.67	-0.88					
	9		0.89						-0.03		0.56						

Table 5. Median estimates (and 95% confidence intervals) of Z and corresponding A values for Striped Bass implanted with an acoustic tag that returned to spawn in the NW Miramichi estuary the following year.

		Fish		Estimate	
Year of tagging	**Survival period**	**Tagged**	**Returned**	**Z**	**A**
2003	2003-2004	19	13	0.38 (0.14 - 0.77)	0.32 (0.13 - 0.54)
2004	2004-2005	21	13	0.48 (0.21 - 0.88)	0.38 (0.19 - 0.59)
2008	2008-2009	20	14	0.36 (0.14 - 0.72)	0.30 (0.13 - 0.51)
2008	2009-2010	14	10	0.34 (0.09 - 0.77)	0.29 (0.09 - 0.54)
2009	2009-2010	21	14	0.41 (0.16 - 0.77)	0.33 (0.15 - 0.54)

Table 6. Fork lengths at age for Striped Bass sampled during their spawning run to the NW Miramichi between 1994 and 2010.

Age		Sample year																
		1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
1	Mean FL			15.0			15.6	18.2		17.9		18.4	17.7	15.5		16.2		
	Range			14.4 - 15.9			11.5 - 24.3	16.1 - 19.8		16.8 - 19.1		16.2 - 21.0	17.1 - 18.3			15.8 - 16.5		
	N			7			6	10		5		41	2	1		4		
2	Mean FL	25.4	26.4	26.7	29.2	25.7	27.8	31.0	29.8	29.8	32.6	30.8	29.6	27.9	29.8	28.5	24.7	25.2
	Range	25.2 - 25.6	25.4 - 28.5	24.1 - 29.8	25.4 - 34.6	23.1 - 28.0	24.5 - 33.0	26.7 - 38.8	25.6 - 34.5	26.3 - 36.8	28.3 - 41.4	27.4 - 33.7	26.3 - 34.1	24.5 - 32.5	25.8 - 35.0	28.1 - 28.8	22.9 - 26.5	23.9 - 26.5
	N	2	3	191	18	19	9	34	43	65	27	30	25	5	19	2	2	2
3	Mean FL	38.2	35.5	36.0	37.3	39.3	40.8	41.5	40.0	43.5	41.9	42.5	42.4	41.0	40.0	42.0	39.6	38.0
	Range	30.7 - 46.1	32.9 - 40.3	27.0 - 38.7	31.6 - 44.1	34.2 - 45.4	30.3 - 48.5	31.5 - 48.0	29.6 - 49.3	29.4 - 48.3	35.2 - 51.2	36.8 - 48.9	38.8 - 45.4	38.8 - 44.8	30.8 - 45.8	34.2 - 47.6	35.2 - 44.5	25.7 - 46.9
	N	754	164	11	95	152	467	131	160	551	133	178	16	15	287	227	107	364
4	Mean FL	46.4	43.8	42.7	45.9	45.6	47.4	49.2	43.2	48.7	49.7	50.2	49.1	46.7	47.2	47.6	48.9	46.7
	Range	41.0 - 49.8	35.1 - 54.8	39.2 -48.2	41.7 - 49.2	37.7 - 52.6	35.4 - 56.2	29.0 - 57.0	34.2 - 55.0	39.5 - 57.5	37.4 - 56.7	42.2 - 57.1	43.2 - 56.8	41.4 - 51.6	41.1 - 52.3	40.6 - 59.2	38.8 - 54.7	35.6 - 58.3
	N	129	382	98	22	68	201	102	327	528	222	72	97	12	51	293	193	47
5	Mean FL	52.9	52.2	51.3	48.8	53.6	52.6	54.7	51.3	54.4	55.1	55.1	53.9	54.6	54.4	52.9	54.1	54.5
	Range		43.0 - 59.2	43.7 - 59.9	47.4 - 49.9	46.5 - 61.3	35.7 - 64.4	47.9 - 63.8	40.1 - 60.5	45.9 - 62.0	45.9 - 65.8	39.7 - 63.3	42.6 - 60.2	48.8 - 60.5	48.1 - 61.1	45.2 - 61.5	45.5 - 62.0	46.7 - 61.9
	N	1	86	350	4	31	93	58	84	211	85	34	36	19	13	123	159	65
6	Mean FL	58.5	57.8	56.6	54.2	61.3	56.5	60.5	57.2	60.1	60.6	61.9	61.1	58.7	57.9	58.2	59.5	59.4
	Range		44.8 - 64.0	47.3 -64.3	49.5 - 62.7	53.7 - 66.6	49.0 - 66.5	53.8 - 72.6	52.4 - 63.5	46.9 - 70.5	52.9 - 65.1	52.4 - 70.5	50.4 - 66.7	53.5 - 64.2	50.7 - 63.7	47.2 - 66.8	52.1 - 66.8	51.8 - 71.0
	N	1	22	20	47	16	21	37	30	68	12	9	17	15	9	25	63	40
7	Mean FL	65.5	65.1			61.2	64.5	63.8	60.0	67.0	68.1	67.4	67.1	62.4	61.8	65.1	65.5	64.6
	Range	65.5 - 65.5				52.3 - 69.5	58.9 - 69.8	53.8 - 68.6	55.0 - 66.0	63.0 - 70.7	56.7 - 72.4	65.5 - 69.5	57.2 - 72.4	51.0 - 67.6	56.3 - 67.4	57.0 - 71.5	58.0 - 72.2	57.1 - 71.5
	N	2	1			20	9	6	14	9	4	4	7	7	8	15	5	19
8	Mean FL	69.9	65.2	66.2			65.4	68.3	64.7	72.0	69.2	75.8		71.7	63.4	68.5	71.2	65.6
	Range		60.5 - 69.8				57.0 - 82.0	51.5 - 74.9	61.2 - 67.2	65.5 - 76.1	60.2 - 76.5			60.5 - 78.0	60.5 - 69.0	58.5 - 74.8	69.3 - 73.5	55.2 - 75.0
	N	1	2	1			8	7	3	9	5	1		5	6	11	6	23
9	Mean FL	74.2			74.9			71.9	71.6	75.3	76.1			76.4	76.1	73.6	74.8	68.7
	Range							63.2 - 80.5	63.5 - 77.0	73.5 - 77.6	74.0 - 78.3			75.0 - 77.7	73.0 - 73.2	66.0 - 82.8	66.3 - 81.6	62.0 - 81.5
	N	1			1			2	4	6	4			2	2	8	7	18
10	Mean FL			72.7		72.4				77.5			82.9			83.8	74.3	74.4
	Range															83.3 - 84.3	64.4 - 85.8	68.3 - 78.6
	N			1		1				1			1			2	3	4
11	Mean FL										80.7	73.2	86.1		73.2		80.6	68.0
	Range											70.2 - 77.5	86.1 - 86.1				76.1 - 85.0	
	N										1	3	2		1		2	1
12	Mean FL		81.7		87.2		88.5			84.7				84.6				83.8
	Range																	80.1 - 87.5
	N		1		1		1			1				1				2
13	Mean FL									80.9								
	Range																	
	N									1								
14	Mean FL																	
	Range																	
	N																	
15	Mean FL														96.4			
	Range														95.8 - 97.0			
	N														2			

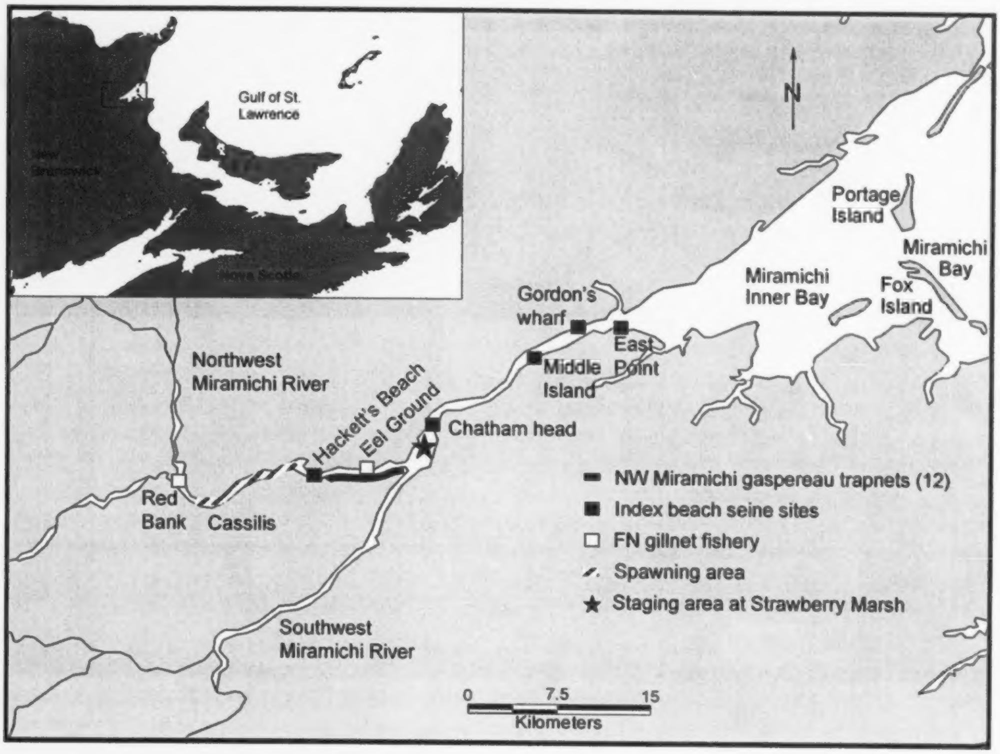


Figure 1. Locations of assessment sampling sites and other ecological points of interest for Striped Bass in the Miramichi estuary.

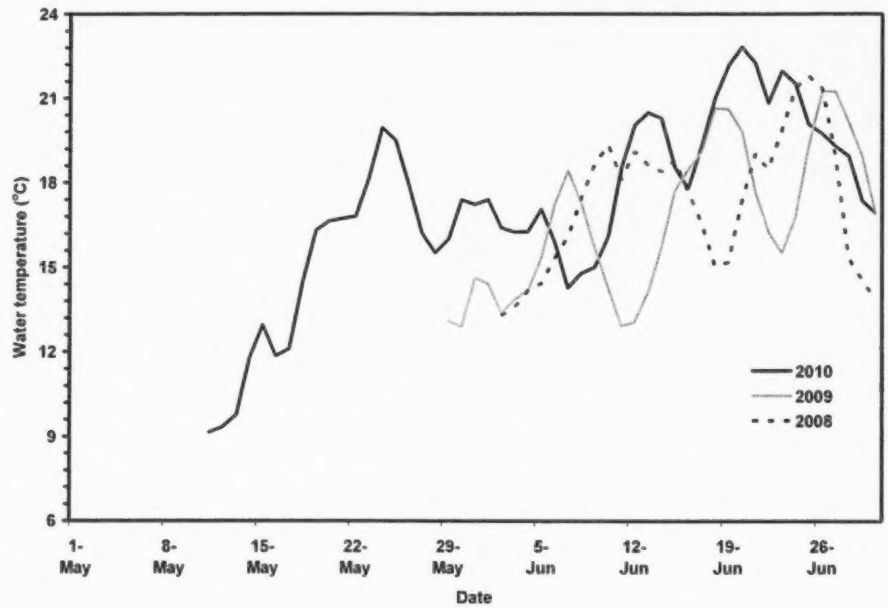


Figure 2. Daily mean water temperatures in the upper portion of the NW Miramichi estuary in 2008-2010. Water temperatures were recorded hourly with a VEMCO data logger installed at a DFO index trapnet on the NW Miramichi River at Cassilis.

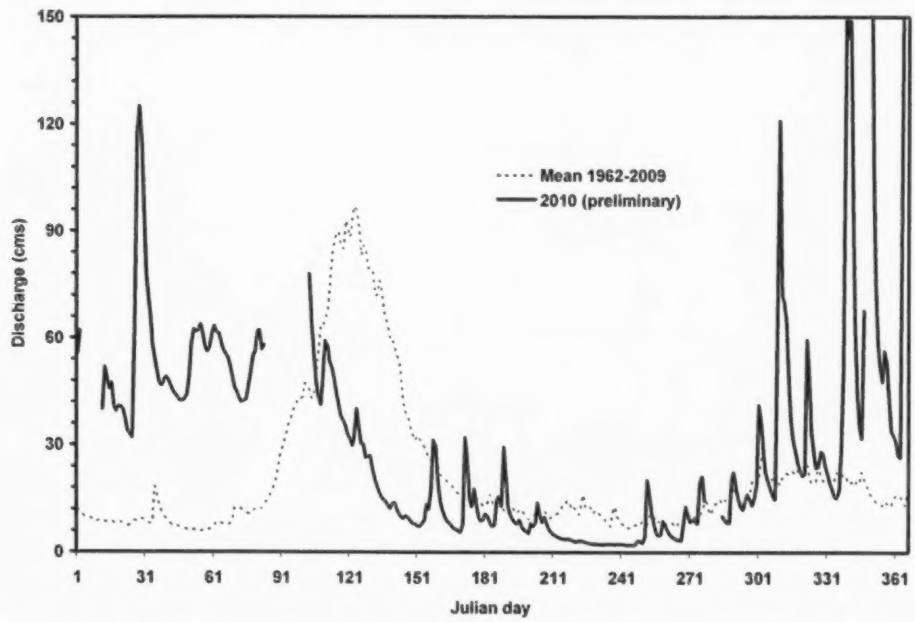


Figure 3. Daily discharge of freshwater on the NW Miramichi in spring 2010 relative to the previous 48 year (1962-2009) average. Julian day 151 represents May 31, 2010.

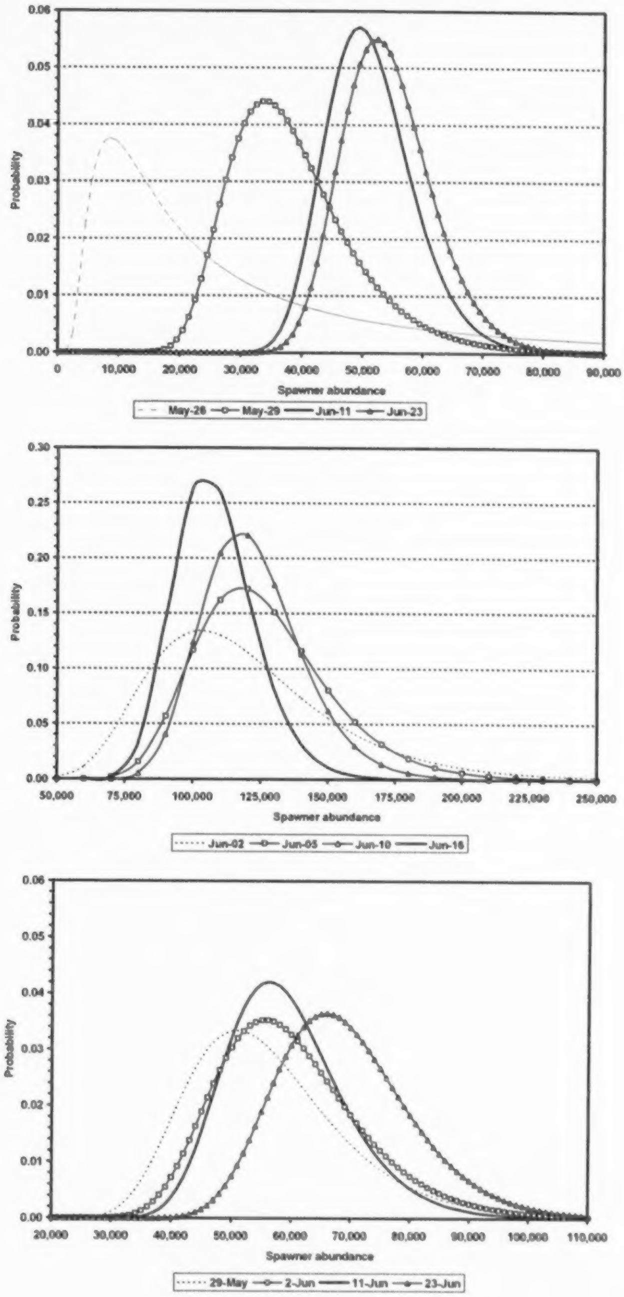


Figure 4. Examples of four sequential estimates of spawner abundance from the mark recapture experiment conducted in 2007 (upper), 2008 (middle), and 2009 (lower) on the NW Miramichi River. The bold lines of June 11, 2007, June 16, 2008, and June 11, 2009 represent the estimate of 49,500, 100,000, and 56,000 spawners in 2007, 2008, and 2009, respectively.

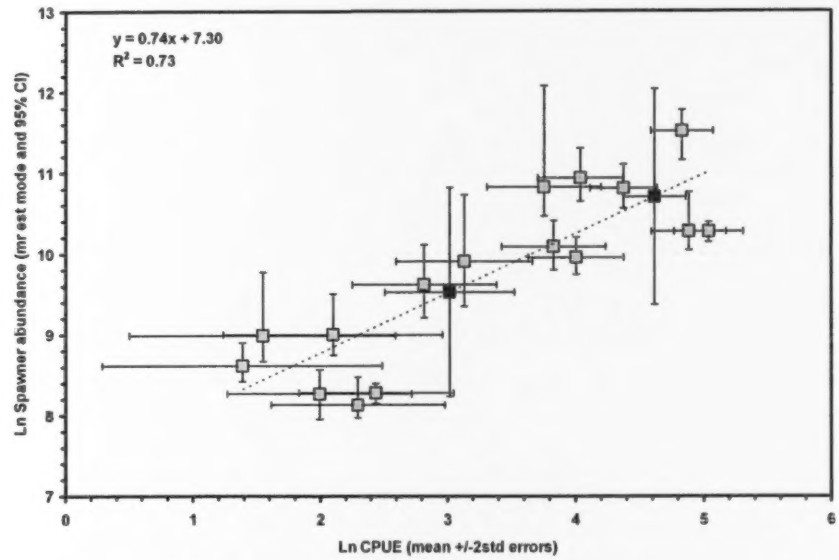


Figure 5. Correlation between two methods used to evaluate Striped Bass spawner abundance returning to the NW Miramichi River between 1993 and 2010. The equation generated from this association was used to estimate spawner abundance in years 2006 and 2010 when the mark recapture data were poor or lacking (black data points).

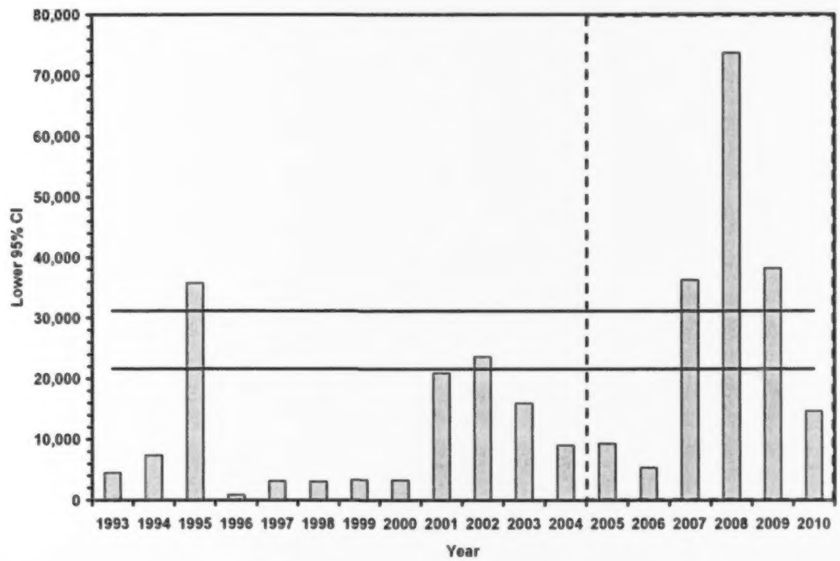


Figure 6. The lower confidence limit of spawner abundance estimates relative to the recovery limit of 21,600 spawners (bottom horizontal line) and recovery target of 31,200 spawners (top horizontal line). The hatched box represents the 6 year sliding compliance window for the recovery objectives.

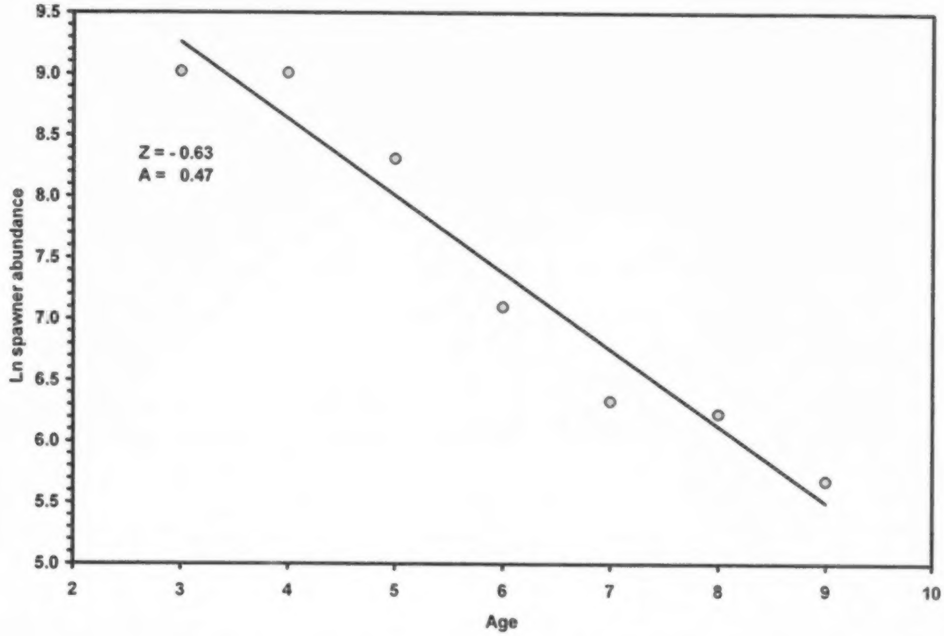


Figure 7. Average mortality of southern Gulf Striped Bass between the ages of 3 and 9 and since the closure of the commercial fishery in 1996.

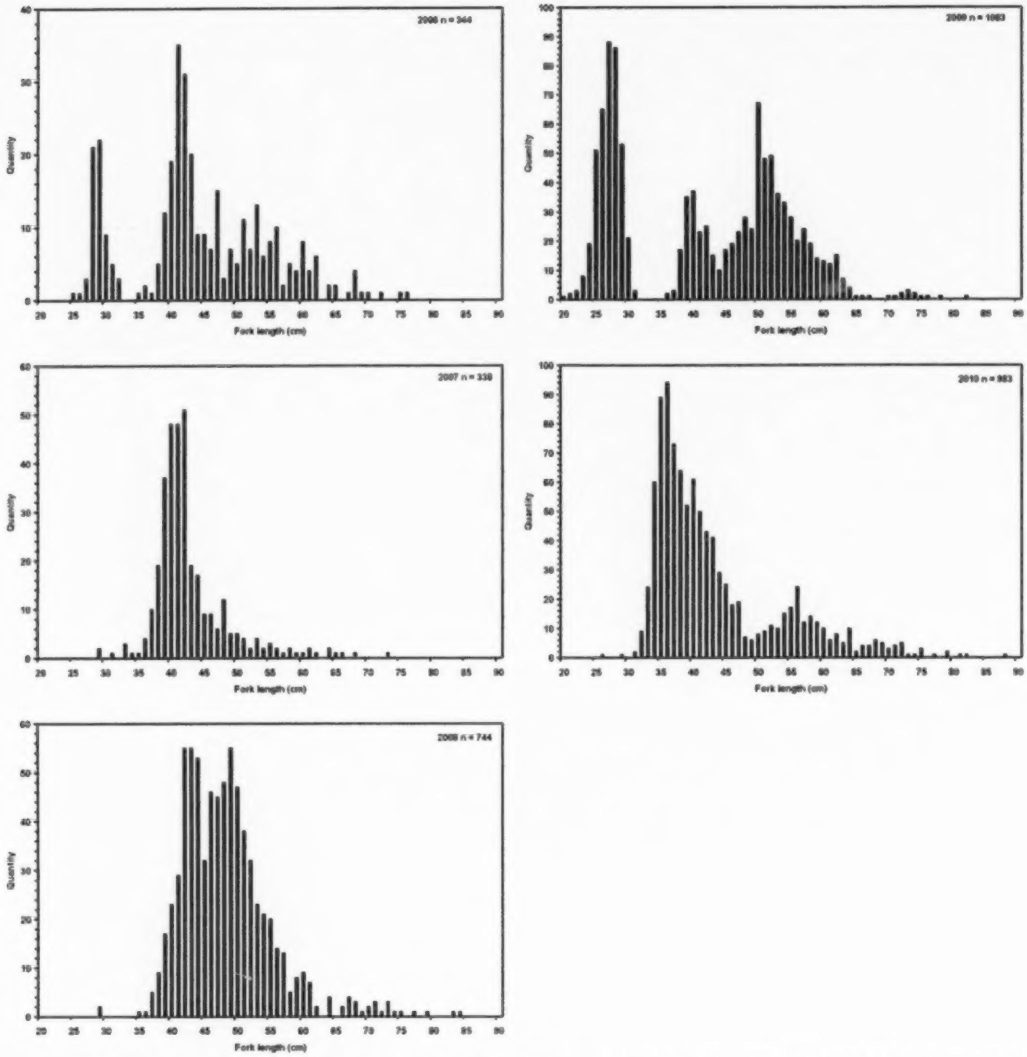


Figure 8. Length frequency distributions of Striped Bass sampled in the NW Miramichi estuary between 2006 and 2010.

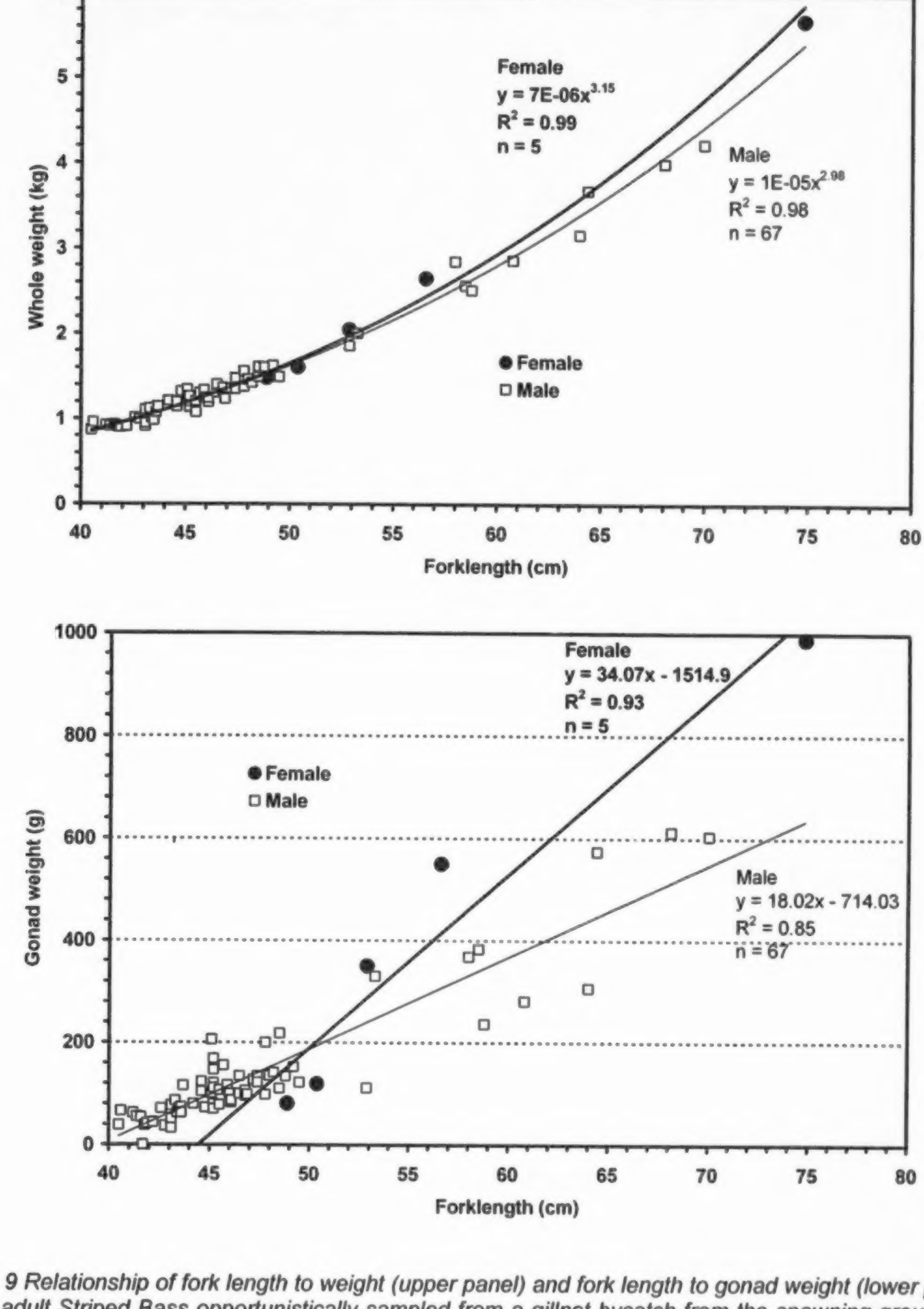


Figure 9 Relationship of fork length to weight (upper panel) and fork length to gonad weight (lower panel) for 72 adult Striped Bass opportunistically sampled from a gillnet bycatch from the spawning grounds of the NW Miramichi River on May 29, 2008.

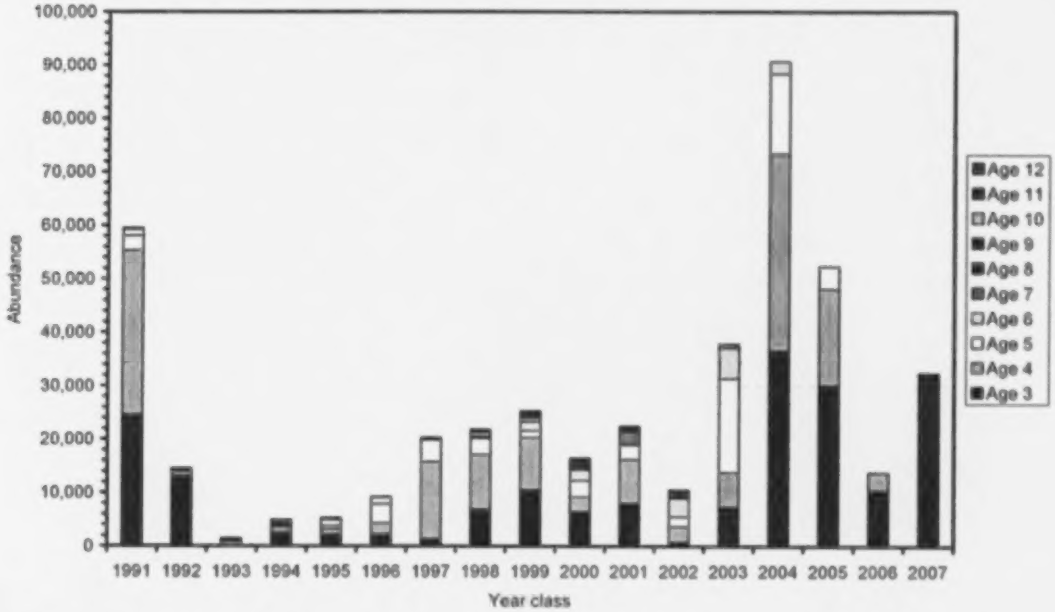
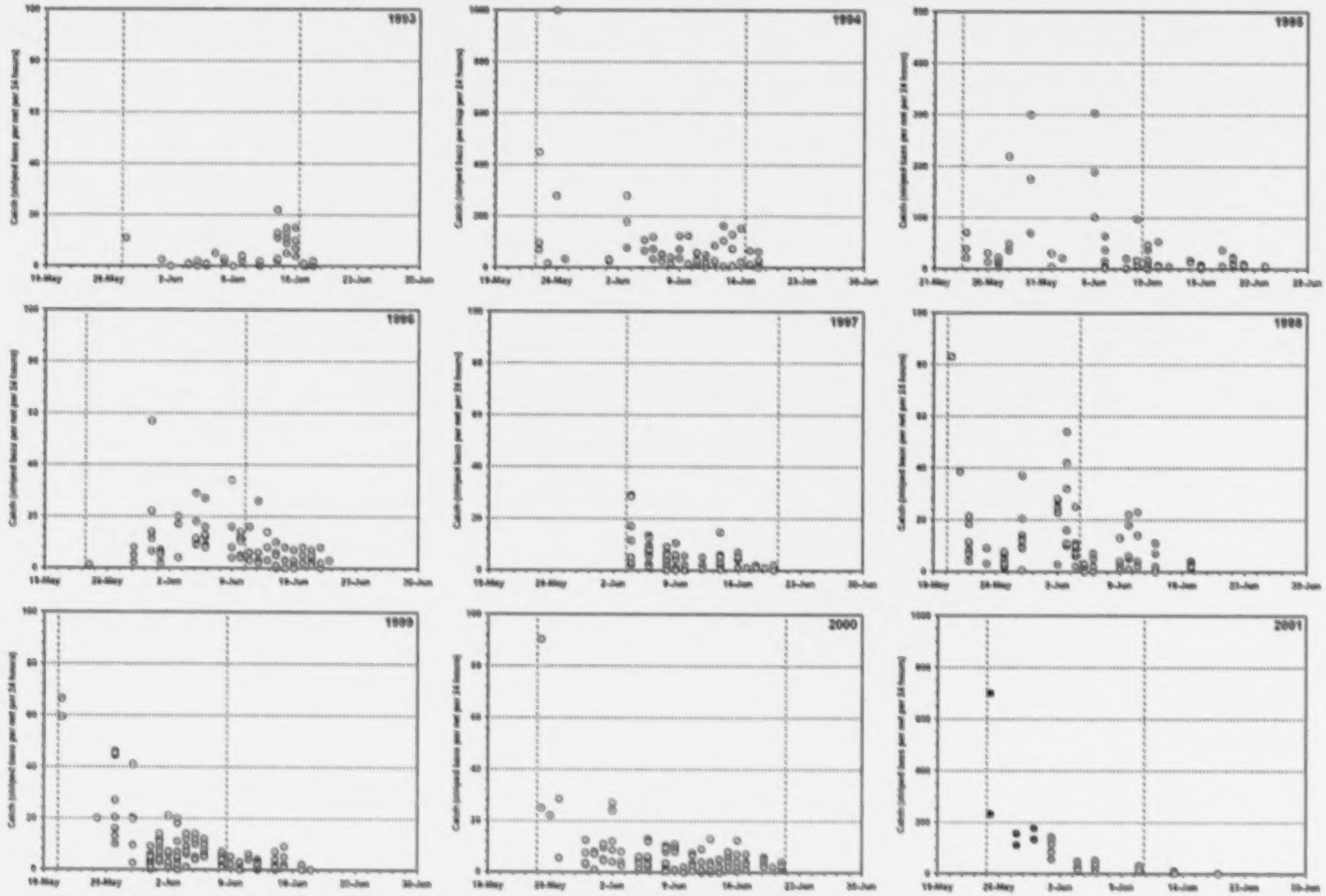
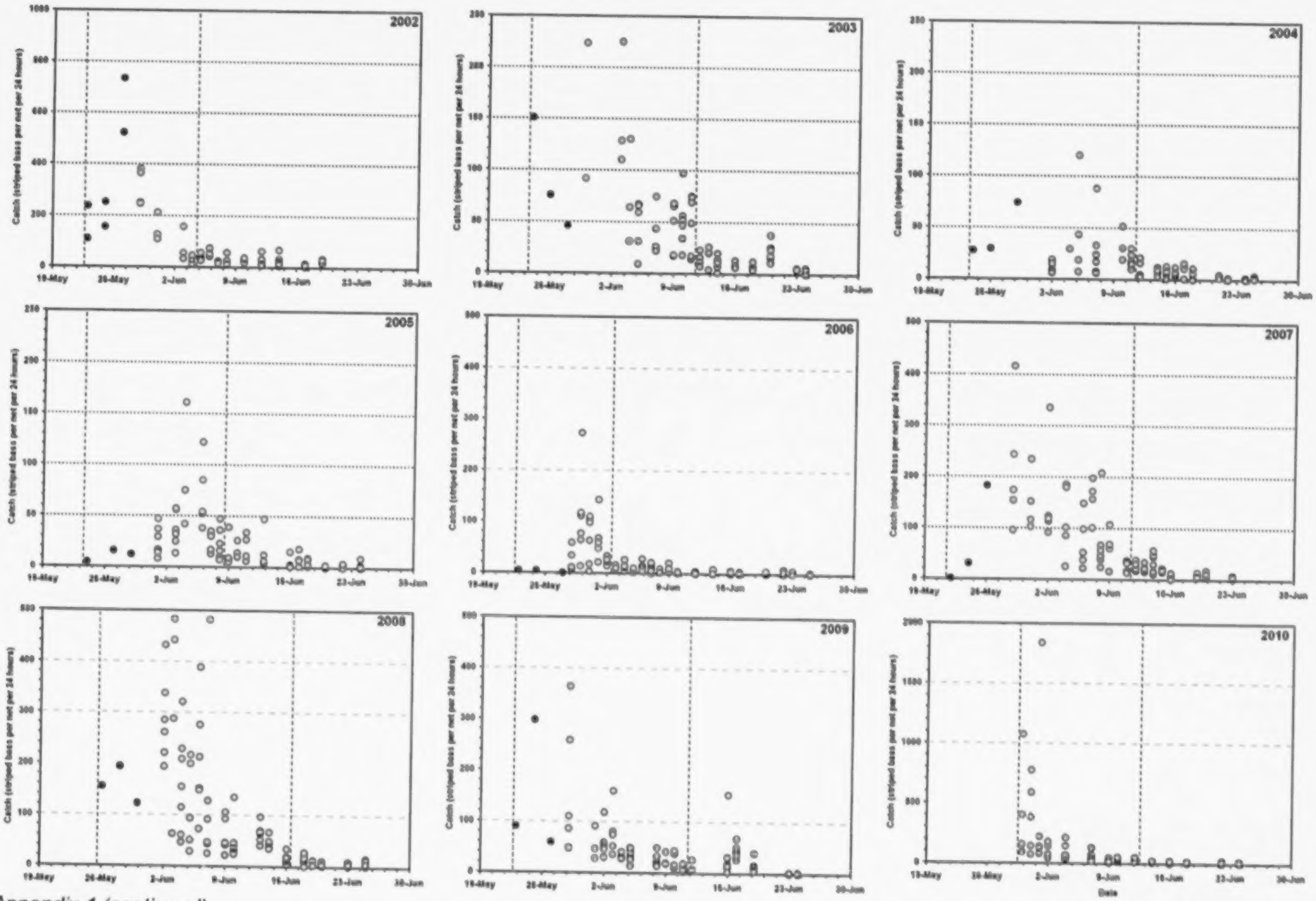


Figure 10. Striped Bass abundance at age and total contribution to the spawning stock for year classes 1991 to 2007.



Appendix 1. Catch of Striped Bass per net per 24 hrs. in commercial trapnets set for gaspereau in the NW Miramichi River, 1993 to 2010. Solid data points indicate Striped Bass tagging events when only one or two trapnets were fished before the official beginning of gaspereau season. Hatched lines encompass the period for the data which are used in the CPUE and mark recapture analyses.



Appendix 1 (continued).